OPTICAL FIBER JOINTS & CONNECTIONS

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OPTICAL FIBER JOINTS

- Technical requirement for both jointing & termination of transmission media

- **Number of Joints or Connections**
  - Link length between repeaters
  - Continuous length of fiber
  - Length of fiber cable practically or conveniently installed as continuous length

- **Repeaters Spacing** (A continuously increasing parameter)
  - Ranges from ≈ 40-60 km at 400 Mbits/s
  - ≈ 100 km at 2.4 Gb/s - SMFs
  - ≈ 300 km at 1.7-10 Gb/s using SMDSFs
FIBER JOINTS

- Source- Fiber
- Fiber- Fiber
- Fiber- Detector

- Manufacturers supply *Electro-optical devices* (Sources and Detectors) with fiber optic *pigtail* or connector to facilitate direct fiber-fiber connection

- IMPORTANT ASPECT IS **FIBER-TO - FIBER** CONNECTION WITH LOW LOSS AND MINIMUM DISTORTION
Two major categories of fiber joints

- **FIBER SPLICES**: Permanent or Semi-permanent joints
  - Soldering

- **FIBER CONNECTORS**: Demountable or Removable joints
  - Plugs or Sockets

- **FIBER COUPLERS**: Branching devices
  - Splitters or Combiners
  - Importance in Networks
Crucial aspect of fiber joints concerning *Optical Losses* associated with the connection

- **Fiber Alignment**

**Loss Mechanisms at Joints**

1. **FRESNEL REFLECTION**

- *Optical Loss encountered at the interfaces* (Even when two fiber ends are smooth, perpendicular to fiber axes and perfectly aligned)

- A small proportion of light may be reflected back into transmitting fiber causing attenuation at the joint.
  - Fresnel Reflection
Reflection Loss

Fraction of light reflected at a single interface

\[
    r = \left( \frac{n_1 - n}{n_1 + n} \right)^2
\]

\(n_1\): R.I. of core, \(n\): R.I. of interfacing medium (= 1 for air)

Loss in decibel due to FR at single interface

\[
    \text{Loss}_{\text{Fres}} = -10 \log_{10}(1-r)
\]

- Can be reduced to a very low level using index matching fluid in the gap between jointed fibers.
2. Deviation in Geometrical & Optical Parameters

- All light from one fiber is not transmitted to another fiber; Because of mismatch of mechanical dimension

Three major cases:

a) Core mismatch

b) NA mismatch

c) Index Profile
Intrinsic Losses

Losses due to:

- Fresnel Reflection
- Deviation in Geometrical & Optical parameters

Minimized using fibers manufactured with lowest tolerance or same fiber
Extrinsic Losses

- Losses due to some imperfection in splicing
  - Caused by Misalignment

Three possible types of misalignment at joint

(a) Longitudinal misalignment
(b) Lateral misalignment;
(c) Angular misalignment
(a) Loss due to lateral and longitudinal misalignment for a 50 μm core diameter GI fiber; (b) insertion loss due to angular misalignment for joints in two MMSI fibers with NA of 0.22 and 0.3.
FIBER SPLICES

A permanent joint formed between two fibers

TWO BROAD CATEGORIES

• Fusion Splicing or Welding
  Accomplished by applying localized heating (a flame or an electric arc) at the interface between two butted, prealigned fiber ends causing them to soften and fuse.

• Mechanical Splicing
  Fibers are held in alignment by some mechanical means
    ➤ Achieved by various methods;
      ○ Tube Splices
      ○ Groove Splices
MUST HAVE SMOOTH AND SQUARE END FACES

- End preparation achieved using suitable tools - “Cleavers”
  “Scribe and Break” or “Score and Break”

- Scoring of fiber surface under tension with cutting tool
  (Sapphire, Diamond or Tungsten Carbide blade)

Optical fiber end preparation: principle of scribe and break cutting.
Fiber Cleavers

Two Action Cleaver:
Fiber cleaving &
Fusion splicing tool

One Action Cleaver

Handheld Cleaver
Cable Preparation Equipment

**Multipack**;

- Enhanced quality to prevent cracks and fiber strength degradation.
- Allow skill-free operation of factory fiber prep and field splicing applications.
- Equipped with a high precision tensile strip and automatic ultrasonic cleaning action.
**Fusion Splicing of Optical Fibers**

- **Manual Processing**
  - Require Fiber end surfaces to be prepared for joint
  - Heating of prepared fiber ends to fusion point with application of axial pressure between two fibers.
  - Positioning & alignment using microscopes

Electric Arc Fusion splicing
Prefusion Method (Automated)

- No need for smooth end preparation

Prefusion method for accurate splicing

- Smaller Fresnel Reflection loss
- Typical Losses: 0.1 to 0.2 dB for MMF
Fusion Splicers
- **Drawback:** Fiber get weakened near splice ($\approx 30\%$)
  - Fiber fracture occurs near the heat-affected zone adjacent to the fused joint.
  - Splice be packaged to reduce tensile loading
Protection of Joints

Protection Sleeves for spliced fibers

Underground fiber splice tray

Fiber joint enclosures
Mechanical Splicing

- Uses accurately produced rigid alignment tubes into which the prepared fiber ends are permanently bonded.

**Techniques for tube splicing of optical fibers:**

(a) Snug Tube Splice
(b) Loose Tube Splice; Square Cross section Capillary
Ultra Splice

Ultra Splice: Reusable mechanical splice.
Average Loss $\approx 0.2$ dB
Groove Splices

- Use of grooves to secure the fibers to be jointed
  - better alignment to the prepared fiber ends.

V-groove splices

- **Insertion losses** $\approx 0.1 \text{ dB}$ using jigs for producing V-groove splice.
Elastic Tube or Elastomeric Splice

- Comprises of two elastic parts (inner with V-groove) in compression to ensure alignment of fibers.

Elastomeric Splice: (a) Cross section (b) Assembly

- Fibers of different diameters tend to be centred and hence successfully spliced.
- General loss ~ 0.25 dB for commercial product
Spring Groove Splice

- Utilizes a **bracket** containing **two cylindrical pins**, which serve as an **alignment guide** for two prepared fibers.

- **An elastic element** (a spring) used to **press the fibers** into groove and maintain alignment of fiber ends.

**Mean Losses** \( \approx 0.05 \text{ dB} \) with MMGI Fibers.

- Practically used in Italy.

**Springgroove Splice**

  (a) Expanded overview

  (b) Cross-section Schematic
Secondary Alignment Techniques

- Alignment of secondary elements around the bare fibers
  - Increased ruggedness
  - Easy ground and polish of fiber end
  - Better termination

**Drawbacks:**

- Time consuming for termination
- Increased losses due to tolerances on secondary elements
  \[\Rightarrow\] Fiber misalignment.
Glass capillary tubes (Ferrules)

- Fixing of glass ferrules
- Alignment sleeve of metal or plastic in which glass tube fibers are aligned
- Average loss $\leq 0.2 \text{ dB}$

Mechanical splice using glass capillary tubes.
Rotary Splice

- Use glass capillary tubes for fiber termination with small eccentricity.

- Built-in offset and rotation, for excellent alignment

- Alignment accuracy of 0.05 μm using three glass rod alignment sleeve. (necessary for SMFs; 8-10 μm MFD)

- **Mean Losses** ≈ 0.03 dB using Index matching gels (Not affected by skill levels of the splicer).

- **Used in large installations in USA**

Rotary Splice for SMF:

(a) Alignment using glass ferrules

(b) Glass rod alignment sleeve
MULTIPLE SPLICES

- Commercially available for splicing number of fibers simultaneously
  - Simultaneous Splicing of Five fibers in 5 minutes;
  - 15 minutes for five single fusion splicing.

- Splice Losses:
  - Ranging 0.04 to 0.12 dB - MM GI fibers
  - 0.13 to 0.4 dB – SM fibers.
A. Silicon Chip Array

- Utilize trapezoidal grooves of a silicon chip using a comb structure for fiber laying and top silicon chip
- End faces ground & polished after curing.

Average Splice loss \( \approx 0.12 \text{ dB} \).

Multiple fibers splicing using a Silicon chip array
B. V-groove flat Chip

- Moulded from glass filled polymer resin
- Direct mass splicing of 12 fiber ribbons with simultaneous end preparation using ribbon grinding and polishing procedures.
- Fibers positioned in grooves in glass filled plastic substrate.
- Vacuum technique to hold fibers at position whilst cover plate is applied.

- Spring clips to hold assembly and hole in cover plate for index matching gel.

- Average Splice Losses
  \[ \approx 0.18 \text{ dB with MM fiber.} \]

V-groove polymer resin ribbon fiber splice.
FIBER CONNECTORS

- Demountable fiber connectors
  - More difficult to achieve than fiber splices
  - Must maintain similar tolerance, but in a *removable fashion*.
  - Must allow for repeated connection and disconnection without problems for fiber alignment - *without degradation in performance*.
  - Must protect the fiber ends from damage – due to handling
  - Must be insensitive to environmental factors (moisture & dust)
  - Must cope with tensile load on the cable and can be fitted with relative ease.
  - Should ideally be a *low cost component*,


Three Major Parts:

- **Fiber Termination**: protects and locates the fiber ends
- **Fiber end Alignment**: provide optimum optical coupling
- **Outer shell**: maintains the connection and fiber alignment, protects the fiber ends from the environment and provides adequate strength at the joint.

➢ **Losses in the range 0.2 to 0.3 dB**
A. Butt Jointed Connectors

- Alignment of two prepared fiber ends in close proximity (butted) to each other so that the fiber axes coincide.
Cylindrical Ferrule Connector

- Glass Ferrules with central drilled hole
- Concentric alignment sleeve

- Preparation of fiber ends before fixing the ferrules
- Insertion Losses \( \approx 1 \) to \( 2 \) dB with MMSIF
- Watch jewel for close end approach and tolerance requirement

**Ferrule Connectors:** (a) structure of a basic ferrule connector; (b) structure of a watch jewel connector ferrule.
Ceramic Capillary Ferrules

- Ferrules made from ceramic material
- End preparation after fixing ceramic ferrules

- Outstanding
  - Thermal,
  - Mechanical
  - Chemical Resistance

- Average Losses
  \[ \approx 0.2 \text{ dB with MMGI} \]
  \[ \approx 0.3 \text{ dB with SMF} \]
Commonly Used Connectors

FC Connectors

ST Connectors

SC Connector
**DIN Connectors**
(Spring loaded free-floating Zirconia ceramic ferrule)

**MTRJ Connector**

**SMA Connector**

**Biconic Connectors**

**D4 Connectors**
Double Eccentric Connector

- Does not rely on a concentric sleeve approach
- Consists of two eccentric cylinders within outer plug.

- An active assembly adjustable, allowing close alignment of fiber ends
- Operation performed under inspection microscope or peak optical adjustment.

Connector Structure

- Mean insertion loss $\approx 0.48$ dB with MMGIFs reduces to 0.2 dB with index matching gel.
  - Also used with SMFs giving losses 0.46 dB.
Multiple Fiber Connectors

- Utilizes V grooved Silicon chips for mounting

- Metal guiding rods and coil springs for precise alignment

- Average Losses
  - \( \approx 0.8 \text{ dB} \) with MMFs
  - Reduced to 0.4 dB using index matching fluids

(a) Fiber ribbon connector  (b) SM Ten fiber connector.
B. Expanded-Beam Connectors

- Utilize interposed optics at the joint to **expand** the beam from the transmitting fiber end before **reducing** it again to a size compatible with the receiving fiber end.

  ➢ Collimating and refocusing the light from one fiber into other.

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**Very attractive for multi-fiber connections and edge connections for PCBs**
Lens Coupled Expanded beam connectors

- Utilize spherical micro-lenses (50 μm Φ) for beam expansion and reduction.

![Diagram of lens coupled expanded beam connectors]

- Average Loss ≈ 1 dB, reduced to 0.7 dB with AR coating.
GRIN-rod Lenses

- An alternative lens geometry to facilitate efficient beam expansion and collimation
  - Arose from development of GI fiber waveguides
  - A cylindrical glass rod 0.5 to 2 mm in diameter with parabolic refractive index profile.
  - Light propagation is determined by the lens dimension and wavelength of the light.
  - Produce a collimated output beam with divergent angle of 1° to 5° from light source onto the opposite face of lens

- Traversing of one sinusoidal period: one full pitch
Various fractional pitch GRIN-rod lenses

- 0.25, 0.23, 0.29 etc.

- SELFOC from Nippon Sheet Glass Co. Ltd.

- Losses $\approx 1$ dB

- Average Losses
  
  $\approx 0.2$ dB with MMGI
  
  $\approx 0.3$ dB with SMF
Fiber Reels, Connectors & Patch cords

Connectors

Patch cords

Adapters

- FC/APC - FC/APC
- SC/PC - SC/PC
- ST/PC - ST/PC
- LC/PC - LC/PC
- E2000
- MTRJ
Fiber Splicing and Connectorization kits
**Bibliography:**

The excerpts of this lecture are based on the information drawn from following references.

4. [www.google.co.in](http://www.google.co.in)
THANK YOU